JACC Vol. 28, No. 4
October 1996:994–9

Low Energy Intracardiac Cardioversion After Failed Conventional External Cardioversion of Atrial Fibrillation

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Objectives. **This study was designed to evaluate the efficacy of intracardiac cardioversion in patients with chronic atrial fibrillation after unsuccessful external cardioversion.**

Background. **Previous studies in patients with atrial fibrillation undergoing intracardiac cardioversion have suggested that intracardiac cardioversion is highly effective and safe. However, the characteristics of patients who benefit most from this invasive technique are unknown.**

Methods. **We prospectively studied 25 consecutive patients with chronic atrial fibrillation (11 ± 9 months). All patients had undergone at least three attempts at conventional external transthoracic cardioversion by means of paddles in an anteroposterolateral position applying energies up to 360 J without success. Intracardiac shocks were delivered by an external defibrillator through defibrillation electrodes placed in the right atrium and coronary sinus or in the right atrium and left pulmonary artery. After conversion, all patients were treated orally with sotalol (mean 194 ± 63 mg/day).**

Results. **Internal cardioversion was successful in 22 of 25 patients at a mean defibrillation threshold of 6.5 ± 3.0 J. Mean lead impedance was 56.4 ± 7.4 Ω. No severe complications were observed. At a mean follow-up of 15 ± 12 months, 12 (55%) of the patients treated successfully remained in sinus rhythm.**

Conclusions. **In patients with failed external cardioversion, internal cardioversion offers a new option for restoring sinus rhythm. Intracardiac cardioversion is an effective and safe method and can be easily performed in patients with minimal sedation.**

(J Am Coll Cardiol 1996;28:994–9)

Atrial fibrillation is a common arrhythmia; its incidence is estimated at 4% to 6% of the U.S. population >60 years old (1–3). Its prevalence is as high as 10% in subjects ≥75 years old (3). Many clinicians previously considered atrial fibrillation a benign arrhythmia; its morbidity and frequently incapacitating symptoms were often underestimated (4,5).

Established methods for converting atrial fibrillation to sinus rhythm include treatment with antiarrhythmic drugs and application of external high energy shocks. Success rates of 40% to 70% have been described with antiarrhythmic drugs (6–11). The reported success rate for external cardioversion ranges from 61% to 90% (12–14). Advanced catheter techniques aimed at restoring sinus rhythm have been evaluated (15–17) in patients with failed external cardioversion and atrial fibrillation not well tolerated despite medication. Internal cardioversion of atrial fibrillation by these techniques used high energies, ranging from 100 to 360 J, and applied either totally right-sided intracardiac or right atrial catheter–chest wall electrode systems.

Recent advances using a coronary sinus and a right atrial catheter-based electrode system for cardioversion of acute atrial fibrillation have proved effective in animals (18–21). After promising results in a pilot study (1) that showed that internal cardioversion is feasible, we focused on a different group of patients with chronic atrial fibrillation who had undergone external cardioversion without restoration of sinus rhythm.

Methods

Patients. We studied 25 consecutive patients with chronic atrial fibrillation at least 2 weeks in duration (mean [±SD] 11 ± 9 months, range 1 to 36) in whom external cardioversion, as described later, failed to restore sinus rhythm. Patient characteristics are described in Table 1.

Study protocol. Patients 21 to 75 years old were enrolled if the following selection criteria were fulfilled: 1) chronic atrial fibrillation of at least 14 days in duration, documented by serial electrocardiograms (ECGs) and 2) effective anticoagulation with warfarin for at least 2 weeks (international normalized ratio [INR] 2.7 to 4.2). Patients were excluded from the study if there was any evidence of digitalis toxicity, abnormal electrolyte levels or hyperthyroidism. Furthermore, patients with an acute myocardial infarction within the past 6 weeks were excluded, as well as patients with a previous history of embolism. Clinical examination was performed, and a medical history was taken. Results of routine 12-lead electrocardiography, 24-h Holter monitoring, chest radiography, M-mode and Doppler echocardiography and routine laboratory and thyroid

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Manuscript received December 15, 1995; revised manuscript received March 20, 1996, accepted May 24, 1996.

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0735-1097/96/$15.00
PII S0735-1097(96)00274-4

Abbreviations and Acronyms

BMI = body mass index
ECG = electrocardiogram, electrocardiographic
INR = international normalized ratio

variables were assessed in all patients. Transesophageal echocardiography was performed if clinically indicated.

The benefits and risks of the study were discussed with all patients. An informed consent form was obtained from all patients based on the protocol and approval of the study by the Ethics Committee of the Klinikum rechts der Isar on April 27, 1993.

Protocol for external conversion. External cardioversion was performed according to the best known established methods (12). Under the supervision of an anesthesiologist, patients were given a short-acting narcotic (methohexital). One to three R wave-triggered shocks of increasing energy, starting with one 200-J shock, a second of 300 J, and, if necessary, a third shock of 360 J (Lohmeier D501, Lohmeier, Inc., Munich, Germany), were applied. We used two paddles placed on the anterior and posterolateral chest wall of the patient. One paddle was placed as posteriorly as possible. Between unsuccessful defibrillation attempts, at least 1 min was permitted to elapse before the next shock was applied. Criteria for quitting were patient discomfort, complications, such as induction of proarryhthmia or skin burns, and a limit of three shocks. If the final 360-J shock failed, internal cardioversion was attempted in a subsequent session.

Protocol for internal conversion. A temporary, custom-built 6F catheter (Elecath) with an active surface of 2.5 cm^2 consisting of nine parallel stainless steel rings was inserted into the right femoral vein and positioned in the lower right atrium so that the majority of the catheter electrodes had firm contact with the right atrial free wall. This catheter served as the defibrillation cathode. Pacing and recording of atrial signals was performed by the distal electrode rings of this catheter. A second defibrillation electrode was placed in either the coronary sinus (Fig. 1) or the left pulmonary artery. In eight patients, the right internal jugular vein was cannulated to place the defibrillation electrode in the coronary sinus. The left pulmonary artery catheter was advanced by either the right antecubital vein or the right femoral vein. Central venous punctures were performed at INR levels up to 2.0 (after warfarin was withheld for 1 to 2 days). Internal cardioversion was performed in the cardiac catheterization laboratory. Sedation was achieved with 5 mg of diazepam orally. Immediately before cardioversion, 2.0 to 8 mg of midazolam was administered intravenously.

Table 1. Clinical Characteristics of 25 Study Patients

Pt No.	Age (yr)/ Gender	Height (cm)	Weight (kg)	BMI (kg/m^2)	LA Diameter (mm)	AF Duration (mo)
1	53/F	160	75	29.3	60	19
2	48/M	172	93	31.4	60	26
3	56/M	192	95	25.8	63	16
4	53/M	170	69	23.9	59	6
5	51/M	176	93	30.0	68	5
6	41/M	195	103	27.1	58	4
7	56/M	181	94	28.2	60	1
8	60/M	185	85	24.8	60	11
9	60/M	179	85	26.5	74	12
10	47/M	182	64	19.3	46	16
11	69/F	172	95	32.1	65	10
12	46/M	185	95	27.8	56	9
13	66/M	185	115	36.3	63	36
14	76/F	163	62	23.3	76	7
15	48/M	172	93	31.4	60	26
16	58/F	165	70	25.7	62	6
17	69/M	179	72	22.5	73	4
18	68/M	174	76	25.1	80	4
19	56/M	168	77	27.3	59	9
20	58/M	176	80	25.8	60	7
21	47/M	185	95	27.8	56	1
22	46/M	176	80	25.8	59	11
23	58/M	180	95	28.2	65	11
24	52/M	183	88	26.3	42	7
25	59/M	180	94	28.1	62	1
Mean	56	177	86	27	62	11
±SD	±9	±8	±13	±3	±8	±9

AF = atrial fibrillation; BMI = body mass index; F = female; LA = left atrial; M = male; Pt = patient.

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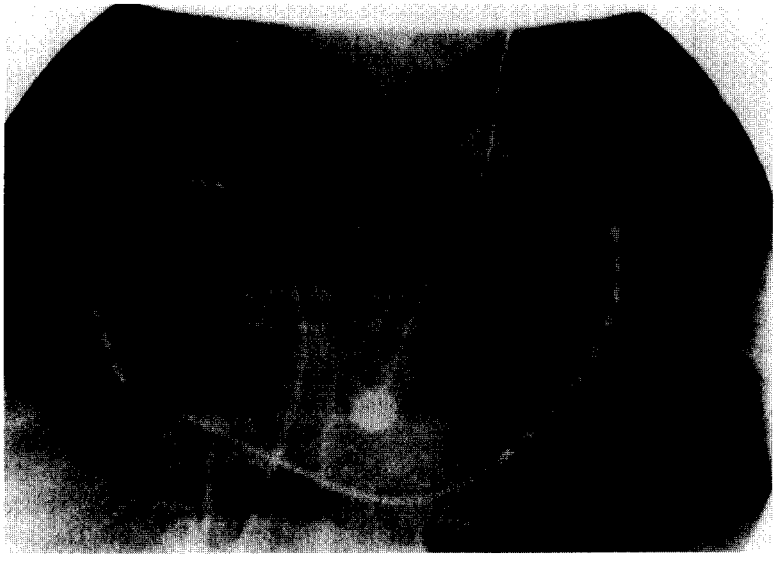


Figure 1. Posteroanterolateral projection in a patient with previous aortocoronary bypass surgery. The right atrial defibrillation catheter is applied through a femoral vein approach. In this patient, a quadripolar catheter for recording of intraatrial signals and stimulation of the atrium is also placed in a low right atrial location through the femoral access. The second defibrillation catheter is placed in the coronary sinus.

Defibrillation threshold was defined as the lowest shock intensity that converted atrial fibrillation to sinus rhythm. Biphasic shocks of 3 and 2 ms with phases separated by 0.2 ms were used. The shocks were delivered by an external defibrillator (Ventritex HVS-02) and synchronized to the R wave. Before application of the shocks, a custom-built ECG amplifier and filter with variable gain was adjusted to ensure correct synchronization, which was confirmed visually on an oscilloscope (Gould 6000 S, Gould, Ilford, United Kingdom). Starting with a test shock of 60 V, the energy was increased in 40-V steps until cardioversion was achieved. Criteria for quitting were patient discomfort, complications such as induction of proarrhythmia and shock energies >15 J. At least 1 min was permitted to elapse between unsuccessful defibrillation attempts, before the next shock was applied. During the study, the 12-lead ECG and intraatrial signals were recorded and stored by EP Lab, Version 6.0 (Quinton Electrophysiology, Inc., Ontario, Canada) (Fig. 2). The voltage delivered, current and shock configuration for each shock were recorded using a Macintosh computer and customized LabVIEW software (National Instruments).

Follow-up evaluation. All patients were seen in our outpatient department. A 12-lead ECG was obtained at the 1-, 3-, 6-, 9- and 12-month follow-up visits or earlier if the patient experienced symptoms suggestive of recurrent atrial fibrillation. After effective cardioversion to sinus rhythm, all patients were treated with sotalol at least 80 mg twice a day (mean 194 ± 63 mg/day, range 160 to 400). Angiotensin-converting enzyme-inhibitors, diuretic drugs and digitalis were also administered according to the clinical status of the patient. In patients with persistent sinus rhythm, anticoagulation was stopped 4 weeks after successful restoration of sinus rhythm.

Statistical analysis. Continuous variables are expressed as mean value ± SD. Statistical analysis was performed using the Mann-Whitney *U* test for unpaired groups. Recurrence data were analyzed using life-table survival analysis. A p value <0.05 was considered statistically significant.

Results

Clinical characteristics and general results. The study included 25 patients (Table 1) (mean age 56 ± 9 years, range 41 to 76; 21 men, 4 women) with a mean body mass index (BMI) of 27 ± 3 kg/m^2 (range 19 to 37), mean duration of atrial fibrillation of 11 ± 9 months (range 1 to 36) and a mean echocardiographic longitudinal left atrial diameter of 62 ± 8 mm (range 42 to 80). External cardioversion had failed in all 25 patients at energies up to 360 J (5 J/kg). Unsuccessful pharmacologic conversion had been attempted in 18 of the 25 patients before external cardioversion (Table 2).

Internal cardioversion was successful in 22 of 25 patients at a mean defibrillation threshold of 6.5 ± 3.0 J and mean lead impedance of 56.4 ± 7.4 Ω. With catheters positioned in the

Figure 2. Surface ECG leads I, II, III, V_1 and V_5 are shown together with the intraatrial recording (**bottom trace,** high right atrium [HRA]). The application of the internal cardioversion shock is synchronous with the R wave. Successful immediate conversion of atrial fibrillation (**left**) to sinus rhythm (**right**) with a 2-J shock was achieved.

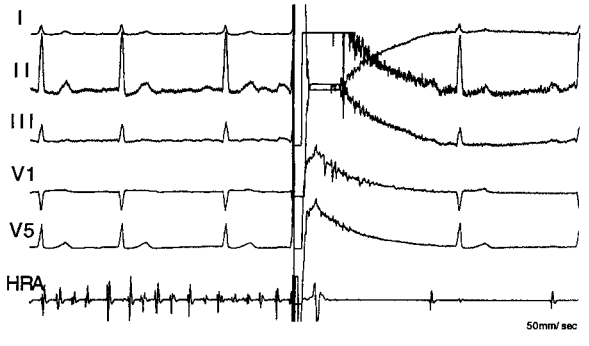


Table 2. Failure of Pharmacologic and External Cardioversion Attempts and Success of Internal Cardioversion

Pt No.	Pharmacologic Agent	External CV Energy (J)	Internal CV DFT (J)	Location of Anode	Internal CV Success	Relapse (mo)	Follow-Up (mo)
1	—	360	3.0	CS	S	7.0	7.0
2	Sotalol	360	4.6	PA	S	2.0	2.0
3	Sotalol	200	9.6	CS	S	1.0	1.0
4	Sotalol	360	4.4	CS	S	—	33
5	Amiodarone	360	6.2	PA	PS	—	32
6	Sotalol	360	3.9	PA	S	6.0	6.0
7	Amiodarone	360	1.6	CS	S	0.8	0.8
8	Sotalol	360	8.1	PA	S	—	31
9	Amiodarone	360	11.1	PA	PS	—	24
10	Sotalol	360	9.3	PA	S	—	30
11	—	360	6.6	CS	S	—	26
12	Amiodarone	360	6.3	PA	S	—	26
13	Sotalol	360	2.0	CS	S	—	25
14	—	360	8.9	PA	S	—	24
15	Sotalol	360	4.6	PA	S	8.0	8
16	—	360	1.8	CS	S	0.3	0.3
17	Amiodarone	360	9.3	PA	S	—	21
18	Sotalol	360	12.7	PA	S	—	15
19	—	360	4.3	CS	S	—	14
20	—	360	7.7	PA	S	0.3	0.3
21	Amiodarone	360	4.6	PA	S	0.5	0.5
22	Sotalol	360	7.8	PA	S	—	11
23	—	360	9.4	CS	NS	—	18
24	—	360	5.4	PA	S	—	10
25	—	360	10.0	PA	S	0.2	0.2
Mean			6.5				15
±SD			±3.0				±12

CV = cardioversion; CS = coronary sinus; DFT = defibrillation threshold; NS = no success; PA = left pulmonary artery; PS = partial success, sinus rhythm <1 min after cardioversion; Pt = patient; S = success.

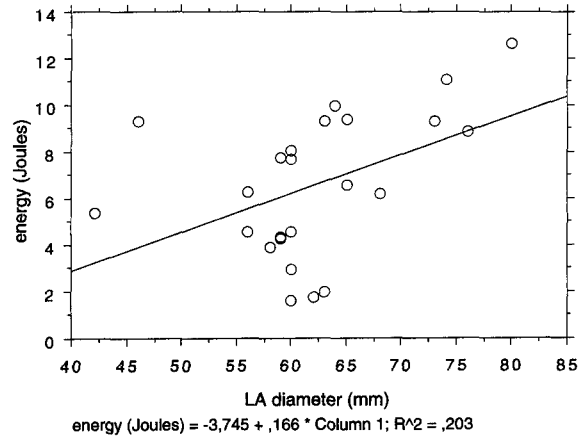
right atrium and coronary sinus, the mean energy for cardioversion was 4.7 ± 3.0 J; for the right atrium and left pulmonary artery configuration, the defibrillation threshold was significantly higher (7.5 ± 2.6 J, $p < 0.05$ by the Mann-Whitney U test).

Short-term efficacy of cardioversion. Table 2 presents the results of external and internal cardioversion. External cardioversion was unsuccessful in all 25 patients; however, internal cardioversion restored sinus rhythm in 22 of 25 patients. In two of the three patients for whom internal cardioversion failed, sinus rhythm was initially restored but was sustained for <1 min despite repeated short-term successful internal cardioversions and postshock pacing.

Correlation of energy requirements with potential clinical predictors. There was a significant positive correlation (Fig. 3) between energy requirements and left atrial size ($p < 0.05$). There was no significant correlation of energy requirements and duration of atrial fibrillation and BMI ($p > 0.05$) in this study.

Long-term clinical outcome. On an intention to treat basis, 12 (55%) of 22 patients successfully treated with internal cardioversion were in sinus rhythm after a mean follow-up of 15 ± 12 months (range 0.2 to 33). In 10 patients, atrial fibrillation recurred after a mean of 1.3 ± 2.0 months. Figure 4 depicts the life-table analysis showing the cumulative proportion of patients remaining in sinus rhythm after successful internal cardioversion.

Figure 3. Correlation of energy requirements and left atrial diameter for successful internal cardioversion of atrial fibrillation ($p < 0.05$).



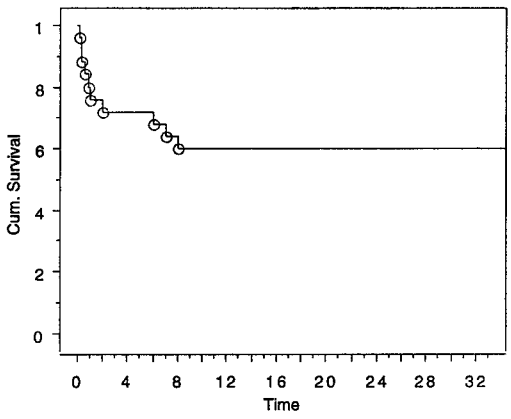


Figure 4. Life-table survival analysis showing the cumulative proportion of patients remaining in sinus rhythm after successful internal cardioversion.

Complications. No severe complications were observed. In one patient, a major femoral hematoma resulted after the procedure. No further treatment was necessary.

Discussion

Main finding. This study shows that internal cardioversion of patients with chronic atrial fibrillation can be achieved even after external transthoracic cardioversion attempts have failed.

Established methods for conversion of chronic atrial fibrillation into sinus rhythm are treatment with antiarrhythmic drugs and external high energy cardioversion during full sedation. Previous reports showed success rates of 40% to 70% (6–11) for antiarrhythmic drugs and 61% to 90% (12–14) for external cardioversion. We found a success rate of 88% for conversion of chronic atrial fibrillation by internal low energy cardioversion in patients in whom attempted external high energy cardioversion had failed.

The exact mechanisms for the higher success rate at lower energies with internal cardioversion can only be inferred. The creation of a homogeneous electrical field with sufficient strength is mandatory for conversion of ventricular fibrillation (22). The same may hold true for atrial fibrillation. With respect to homogeneity of field strength, one would assume that the direct application of the energy to the right atrium and near the left atrium (coronary sinus, left pulmonary artery) should result in increased myocardial field strength and decreased energy loss. This may also explain in part why previous attempts of high and low energy shocks delivered between one electrode in the heart and one skin electrode (15) or between electrodes not incorporating the left side of the heart (16,18) had less favorable results than the method of internal cardioversion described here.

In contrast to the energies required for conversion of induced atrial fibrillation in animals and humans, which range from 0.5 to 2.2 J on average (18–21,23,24), we used higher energy levels (mean 6.5 ± 3.0 J) in our patients with chronic atrial fibrillation after failure of external cardioversion. This may be explained in part by the longer duration of atrial fibrillation in our patients and by the use of the pulmonary artery electrode location, all of which could have resulted in a higher actual energy requirement (25–27). In our previous report of internal cardioversion in a different group of patients, we used lower energy levels (mean 3.7 ± 1.7 J) (1). In that pilot study, only 7 of the 14 patients had undergone previous unsuccessful external cardioversion attempts; furthermore, in the majority of patients a coronary sinus lead configuration was chosen. This choice of configuration might explain the higher energy levels for successful internal cardioversion in the present study. Characteristics such as a dilated atrium and high BMI (>25 kg/m^2), like those encountered in our patients, are the main reasons for failure of external high energy cardioversion (12–15). These are the patients who may especially benefit from internal cardioversion. Our data show that internal cardioversion is worthwhile and highly effective even after failed external cardioversion attempts. These patients have an 88% success rate for regaining sinus rhythm by this new method after established treatments have failed.

In addition to the high success rate the major advantage of internal cardioversion compared with external high energy shock application is that the energy for internal cardioversion is much lower than that normally applied with conventional external direct current cardioversion. Therefore, atrial cardioversion can be performed without general anesthesia, and the supervision of an anesthesiologist is not necessary. Nonetheless, the mean atrial defibrillation threshold of 6.5 ± 3 J is still far above the pain threshold for most patients, but the procedure was well tolerated with a low dose of diazepam and midazolam.

Follow-up. After cardioversion, all our patients were treated with oral sotalol on the basis of positive reports describing a high maintenance rate of sinus rhythm after direct current cardioversion of atrial fibrillation with this drug (10,11,28). Our follow-up data confirm these findings and show that the relapse rate of atrial fibrillation is comparable to that after external high energy cardioversion (6).

Limitations of internal cardioversion. With any type of energy application to the heart at or exceeding the pacing threshold, there is some risk of inducing arrhythmia, even with synchronized shocks (29,30). This new method of internal cardioversion is highly effective but nonetheless requires the insertion of catheters into the vascular system in patients during anticoagulation. It is an invasive technique, and all risks and limitations have to be considered.

Positioning of defibrillation electrodes in the right atrium, pulmonary artery or coronary sinus raises the question of whether damage can result from the energy delivered through the defibrillation electrodes. Long-term implantation of defibrillation electrodes in the coronary sinus and other locations in the heart has been used without adverse effects for shock application of energies up to 30 J for treatment of ventricular fibrillation in patients (31,32). Therefore, it is unlikely that atrial defibrillation from these sites would result in myocardial damage and is supported by the observation that creatinine

kinase levels did not show significant changes after internal cardioversion.

Study limitations. This study is part of an ongoing randomized trial for comparison of different lead positions for internal cardioversion of atrial fibrillation. In the present study, we presented data for patients with failed external cardioversion only. More of these patients had leads in the left pulmonary artery than in the coronary sinus. Preliminary data show that patients assigned to a defibrillation lead in the coronary sinus have lower thresholds than those with leads located in the left pulmonary artery (33). The atrial defibrillation threshold of 4.7 J with a coronary sinus lead in our study correlates well with recently published results of a multicenter trial (34) that used a mean conversion voltage of 313 V (3.5 J) of chronic atrial fibrillation using right atrial and coronary sinus defibrillation electrodes.

Clinical implications. In nearly 90% of patients in whom external cardioversion fails, internal cardioversion will be successful, and >50% of these patients will maintain sinus rhythm over the long term. Therefore, we recommend low energy intracardiac cardioversion for all patients with failed external transthoracic cardioversion attempts as an effective additional method to restore sinus rhythm.

We are grateful to Trey Ideker, MSE and Jay Pasquantonio, BSE for valuable technical assistance in conducting the study.

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